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Precipitation alters temperature effects on ecosystem respiration in Tibetan alpine meadows

Jingxue Zhao[a,b], Tianxiang Luo[b,**], Ruicheng Li[a], Haixia Wei[b], Xiang Li[b], Mingyuan Du[c], Yanhong Tang[a,*]

[a] Department of Ecology, College of Urban and Environmental Sciences, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, Beijing 100871, China
[b] Key Laboratory of Alpine Ecology and Biodiversity, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Beijing 100101, China
[c] Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization, Tsukuba 3058604, Japan

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ABSTRACT

There is scant evidence for the interactive effect of warming and precipitation change on ecosystem respiration (Re), particularly regarding for alpine meadow ecosystems where there are high belowground biomass and soil organic carbon stocks. Such knowledge is crucial for predicting terrestrial carbon cycling under climate change. We transplanted meadow blocks reciprocally among three altitudes (4650 m, 4950 m and 5200 m) in the central Tibetan Plateau and examined the controls on Re in 1.5 and 2.5 years after the transplantation. Under the same degree of experimental warming by the downward transplantation, the Re increased and decreased significantly when the precipitation was higher and lower at destination sites than at the home sites, respectively. However, the experimental cooling by the upward transplantation consistently reduced the Re regardless of the precipitation change. Further analysis showed that the increase of Re under the experimental warming was closely related to the increase of aboveground biomass, whereas the reduction of Re under the cooling was highly correlated with the decrease of soil temperature. Moreover, the temperature sensitivity of the Re was decreased by the experimental warming but increased by the experimental cooling. These results suggest that effects of climate warming on the ecosystem respiration are highly associated with precipitation changes in the temperature-limited meadow ecosystems.

1. Introduction

Global mean temperature is expected to increase with concomitant changes in precipitation in the 21st century (IPCC, 2014). The changes of temperature and precipitation will affect the carbon fluxes between terrestrial ecosystems and atmosphere (Heimann and Reichstein, 2008; Wu et al., 2012). Alpine meadows, covering extensive areas in the high-altitude ecosystems, have long been regarded as one of the most vulnerable ecosystems to climate change. First, some studies found that recent climate warming is generally faster at higher altitudes (Beniston et al. 1997; Mountain Research Initiative EDW Working Group, 2015). Secondly, alpine meadows often have high proportion of belowground biomass and/or high soil organic carbon stocks. There is thus growing concern that the ecosystem respiration (Re) in particular the soil respiration will be accelerated under the fast temperature elevation in alpine meadows (Chen et al., 2016b; Bosch et al., 2017). Recent studies have perceived that the potential change of the Re with warming is highly associated with other climatic factors (Lu et al., 2013; Wang et al., 2014). Most of these studies, however, have focused only on the effect of either temperature or precipitation (Wu et al., 2011; Liu et al., 2016). Knowledge of interactive effects of temperature and precipitation on Re is needed for understanding the carbon cycle of alpine meadow ecosystems in response to climate changes.

Changes of ecosystem respiration depend greatly on environmental temperature and precipitation (Davidson et al., 1998; Wu et al., 2011; Liu et al., 2016). Experimental warming generally increases the Re due to increasing plant biomass, litter decomposition and microbial activity (Rustad et al., 2001; Lu et al., 2013; Wang et al., 2014). Increasing precipitation can also increases the Re in general in water-limited ecosystems (Wu et al., 2011; Liu et al., 2016). It is noticed that warming

* Corresponding author at: Department of Ecology, College of Urban and Environmental Sciences, and Key Laboratory for Earth Surface Processes of the Ministry of Education, Peking University, No. 5 Yiheyuan Road, Haidian District, Beijing 100871, China.
** Corresponding author at: Key Laboratory of Alpine Ecology and Biodiversity, Institute of Tibetan Plateau Research, Chinese Academy of Sciences, Courtyard 16, Building 3, Lincui Road, Chaoyang District, Beijing 100101, China.
E-mail addresses: luotx@itpcas.ac.cn (T. Luo), tangyh@pku.edu.cn (Y. Tang).

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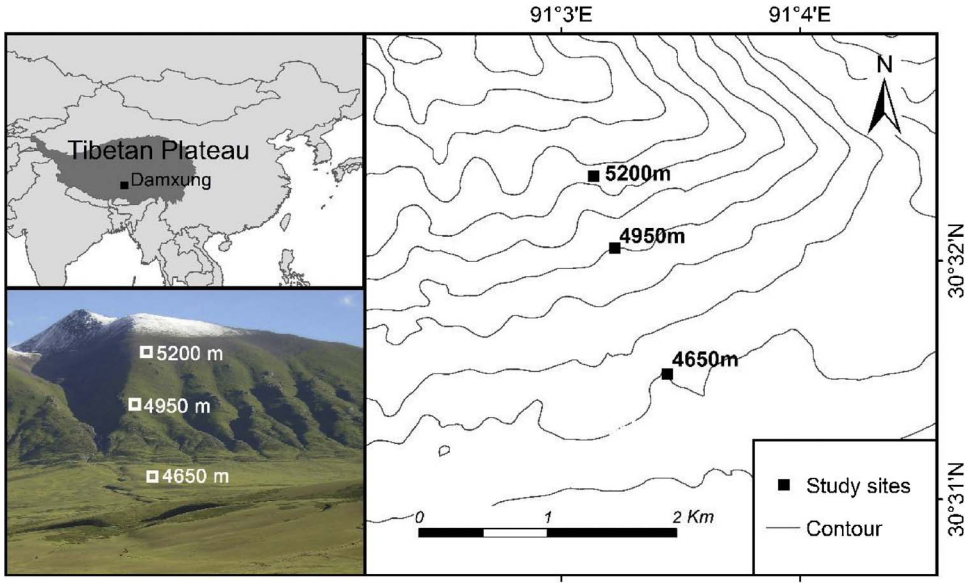

Fig. 1. Diagram of the landscape and experimental sites along the south-facing slope of Nyaiqentanglha Mountains on the Tibetan Plateau.

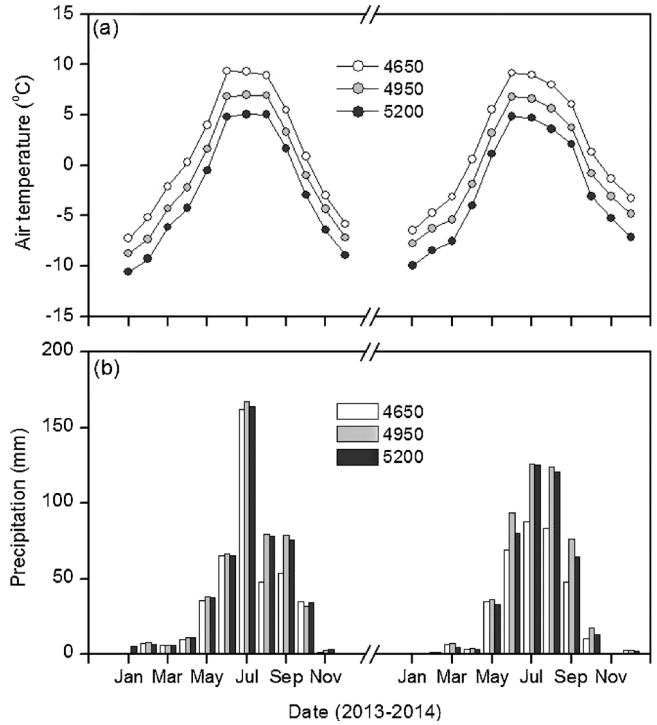

Fig. 2. Seasonal changes in (a) monthly mean air temperature and (b) monthly precipitation at 4650 m, 4950 m and 5200 m during 2013 and 2014.

effects on Re depend strongly on temperature-moisture interactions or on precipitation in grassland ecosystems (Flanagan and Johnson, 2005). A combination of warming and decreased precipitation may largely reduce soil organic carbon (Angert et al., 2005; Ciais et al., 2005). However, very little information is available for evaluating temperature and precipitation interactions on the Re in alpine meadow ecosystems.

The alpine meadow on the Tibetan Plateau has been considered to be sensitive to global warming (Cao et al., 2004; Yang et al., 2008). The plateau has become warmer and wetter in recent decades, and the warming magnitude is much larger than surrounding areas (Liu and Chen, 2000). Temperature elevation on the plateau is often accompanied by precipitation change (Li et al., 2004; Hu et al., 2016). Some studies have already paid attention to the possible consequences of climate warming on the carbon cycle in the alpine meadow ecosystem, but evidences are inconsistent. Fu et al. (2013) found that experimental warming decreases Re due to warming-induced drying, while other studies report different effects of warming on Re (Lin et al., 2011; Hu et al. 2016). No evidence exists to clarify the interactive effect of warming and precipitation change on the Re in the alpine meadow ecosystem on the Tibetan Plateau.

To examine the combined effect of changes in temperature and precipitation on Re, we transplanted meadow blocks reciprocally along an altitude gradient of Nyaiqentanglha Mountains in the central Tibetan Plateau. Previous studies have provided basic ecological information for the altitude gradient including plant phenology, species distribution, biomass production, soil properties and even the Re observed under natural conditions (Li et al., 2013b, 2016; Wang et al., 2013; Zhao et al., 2016). In this study, we focused our attention only on the *Kobresia pygmaea* meadows, which is one of the meadow vegetation types distributed most extensively in the high mountains on the plateau. Our objectives were: 1) to determine the effects of experimental warming and cooling on Re; 2) to evaluate the combination effects of altered temperature and precipitation on Re; and 3) to assess the relationship of warming and cooling with the temperature sensitivity of Re (Q_{10}).

2. Materials and methods

2.1. Study sites

The experiment was conducted on the south-facing slope of Nyaiqentanglha Mountains (30°30′–30°32′ N, 91°03′ E; 4650–5200 m a.s.l, Fig. 1), central Tibetan Plateau. This region has a semi-arid climate, characterized by Indian monsoon in summer and the westerlies in winter. According to meteorological observations from 1963 to 2010 at Damxung station (4288 m, ca. 4 km from the study site), annual precipitation was 479 mm and annual mean air temperature was 1.8 °C. During 1963–2010, annual mean air temperature has increased by 1.6 °C, but the trend of annual precipitation varies with timescales, with a decreasing trend from 1963 to 1990 and an increasing trend from 1991 to 2010 (Wang et al., 2013).

Along the slope, the typical alpine meadow dominated by *Kobresia pygmaea* is found in altitudes between 4650 m (lower limit) and 5200 m (upper limit), with a distribution center at ca. 4950 m (Wang et al., 2013). Other coexisting species mainly include *Androsace tapete*, *Kobresia humilis*, *Kobresia humilis*, *Polygonum macrophyllum*, *Potentilla saundersiana*, *Thalictrum alpinum* etc. The vegetation cover is about

Table 1
Growing-season mean air-temperature (GST) and precipitation (GSP), soil temperature (T_s), soil moisture (M_s), aboveground biomass (AGB), soil organic carbon content (SOC), ecosystem respiration (Re) and temperature sensitivity of Re (Q_{10}) for the home sites across three altitudes. Different letters between altitudes indicate the significant difference at 0.05 level. Values in parentheses indicate SE of mean.

Variables	Altitude (m)		
	4650	4950	5200
GST (°C)	8.1 (0.4)^a	5.8 (0.3)^b	3.9 (0.3)^c
GSP (mm)	319 (25)^a	421 (2)^b	390 (12)^b
T_s (°C)	17.2 (1.8)^a	14.6 (1.6)^b	12.6 (1.4)^b
M_s (%)	17.1 (2.3)^a	28.5 (1.6)^b	23.8 (1.4)^c
AGB (g m^{-2})	364.7 (69.8)^a	419.7 (59.2)^b	293.0 (33.1)^c
SOC (g kg^{-1})	44.7 (6.6)^a	110.7 (8.5)^b	69.5 (8.2)^c
Re (μmol m^{-2} s^{-1})	2.88 (0.26)^a	4.04 (0.13)^b	2.40 (0.35)^c
Q_{10}	2.23 (0.22)^a	2.92 (0.20)^b	2.73 (0.18)^b

50–90% and the canopy height is generally less than 10 cm. The grassland turns green in late May to late June when monsoon rainfall arrives and the aboveground biomass typically peaks in late July to mid-August (Li et al., 2016; Zhao et al., 2016). Pasture for domestic yaks and sheep is the main land-use type in this region. In August 2005, HOBO weather stations (Onset Inc., Bourne, MA, USA) were set up at 4650 m, 4950 m and 5200 m. Air temperature (1.5 m aboveground) and precipitation were recorded by the HOBO data logger at 30-min intervals. To characterize altitudinal environments along the slope, the data for monthly mean air temperature and precipitation during 2006–2014 were obtained from the HOBO stations at each of the 3 altitudes.

2.2. Experimental design

Three 20 m × 20 m plots were fenced at 4650 m, 4950 m and 5200 m to avoid livestock grazing. The experimental areas were chosen to be limited within *Kobresia pygmaea* meadow. In September of 2011, 18 intact meadow blocks (70 cm in length and width and 40 cm in depth) per altitude were cut off for reciprocal transplantation among the three altitudes (Fig. 1). Since the majority of root biomass is found in the top 20 cm of soil with little below 30 cm (Wang et al., 2013), we cut the blocks at soil depth of 40 cm to avoid any significant damage to roots. For each altitude, 6 blocks were reinstated at the same altitude as control plots (home sites), and another 12 blocks were transferred to the other 2 altitudes (destination sites, 6 blocks per altitude).

2.3. Measurement of ecosystem respiration (Re)

At the beginning of measurement (in early May of 2013), a polyvinyl chloride (PVC) collar (diameter: 20 cm; height: 5 cm) was set in each of the transplanted blocks. The PVC collars were inserted into the soil carefully to avoid disturbing soil structure, with 2 cm remaining above the ground surface. Re was measured on sunny days at 08:00–18:00 local time during the growing season from June to September. Measurements were conducted at 2 h interval once a month in 2013 and twice a month in 2014, using the opaque chamber of Li-8100 103 automatic soil CO_2 flux system (LI-COR Biosciences, Lincoln, NE, USA). To determine the differences in soil temperature (T_s) and moisture (M_s) among altitudes, T_s and volumetric M_s of –5 cm at each collar were measured simultaneously with Re using a digital temperature sensor (Type E, OMEGA Engineering, Inc., Stamford, CT, USA) and a Time Domain Reflectometer with a handheld push probe (Type ML2x,

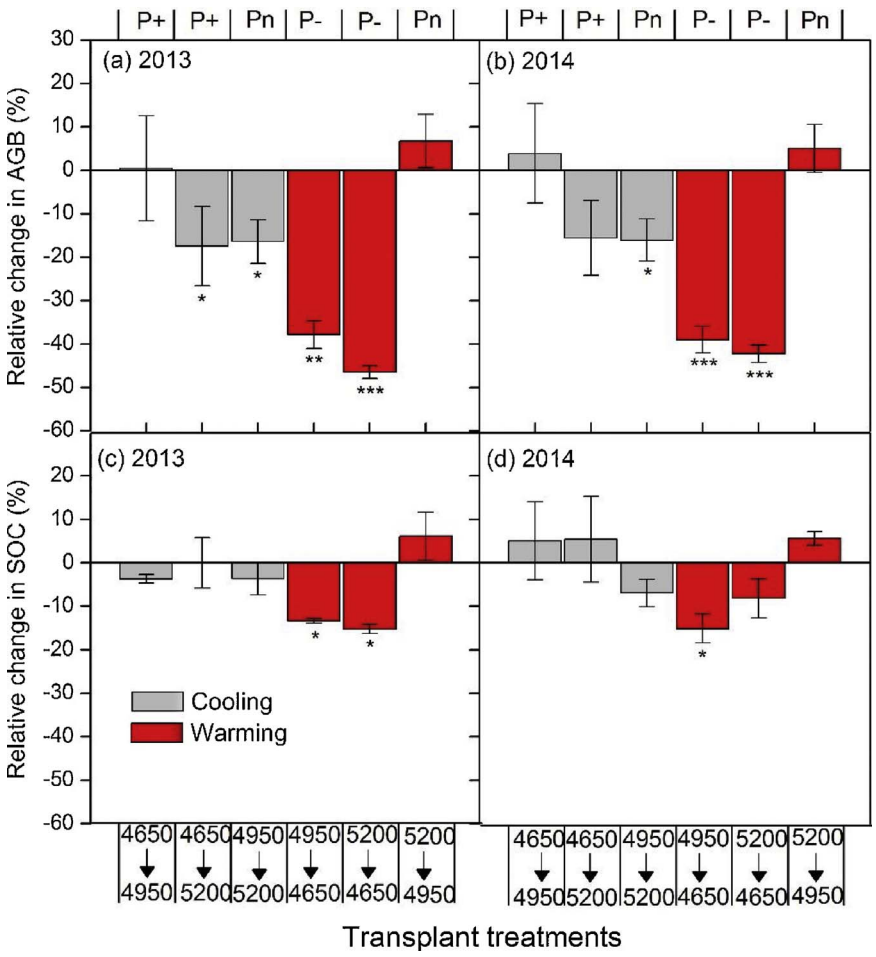

Fig. 3. The relative changes (%) in AGB and SOC between translocated sites and control sites (home-sites) along the altitudinal gradient. (a–b) The relative change in AGB during 2013–2014; (c–d) the relative change in SOC during 2013–2014. P+, precipitation increased; P–, precipitation decreased; Pn, precipitation unchanged. Mean ± SE is shown in error bars. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

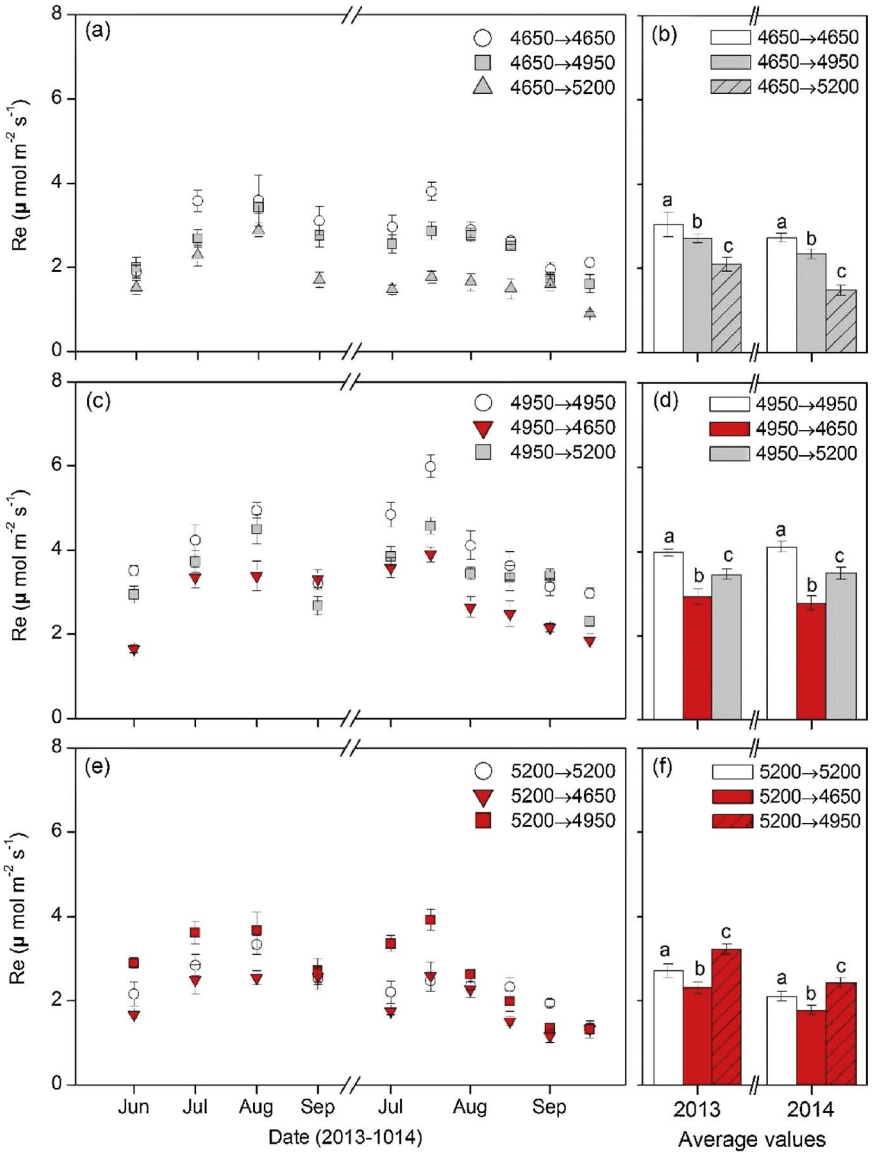

Fig. 4. Seasonal differences in ecosystem respiration rate (Re) between control and translocated sites during the growing seasons of 2013 and 2014. (a–b) Seasonal variation (a) and the average (b) of Re at the sites transplanted from 4650 m to 4650 m, 4950 m and 5200 m; (c–d) Seasonal variation (c) and the average (d) of Re at the sites transplanted from 4950 m to 4950 m, 4650 m and 5200 m; (e–f) Seasonal variation (e) and the average (f) of Re at the sites transplanted from 5200 m to 5200 m, 4650 m and 4950 m. Different letters indicate the significant difference among transplanted treatments at 0.05 level.

Delta-T Devices Ltd, Burwell, Cambridge, United Kingdom). The data sets from the portable instruments were calibrated with HOBO weather stations before being analyzed.

2.4. Measurement of aboveground biomass and soil organic carbon

For each square of 50 cm × 50 cm within a transplanted block, we measured species-specific plant height and percentage cover in mid-August of 2013 and 2014. We estimated the species-specific aboveground biomass (AGB) using the empirical equations between AGB and vegetation volume (i.e. the product of plant height and cover) developed by Wang et al. (2013), given that the measured vegetation volume, i.e. the product of plant height and cover can serve as a substitute for AGB in grasslands. We collected top soil samples (0–10 cm in depth) with a soil auger (diameter: 3.0 cm) from each quadrat immediately after the above measurement. After removing visible roots, soil samples were air-dried at room temperature and sieved for measuring soil organic carbon (SOC) according to the Walkley and Black dichromate oxidation method (Nelson and Sommers, 1982).

2.5. Statistical analysis

We use Van't Hoff exponential equation (Lloyd and Taylor, 1994) to describe the relationship between soil temperature and ecosystem respiration:

$$Re = \alpha e^{bT} \quad (1)$$

Where, Re is the ecosystem respiration, α is the respiration rate at 0 °C, b is a temperature-response coefficient, and T is the soil temperature. According to Lloyd and Taylor (1994), the temperature sensitivity of Re (Q_{10}) can be estimated from the coefficient b in Eq. (1) as follows:

$$Q10 = \frac{\alpha e^{b(T+10)}}{\alpha e^{bT}} = e^{10b} \quad (2)$$

Independent Sample t-test was used for testing the differences in AGB, SOC, and seasonal mean T_s, M_s, Re and Q_{10} between the home sites and the destination sites. One-way analysis of variance (ANOVA) and the Tukey-HSD test were applied to assess the differences in growing-season mean air-temperature (GST) and precipitation (GSP), T_s, M_s, AGB, SOC, Re and Q_{10} for control sites among the three altitudes. The relative change in T_s, M_s, AGB, SOC, Re or Q_{10} due to transplantation between altitudes was calculated as: Relative change (△, %) = 100 × (Translocated – Control) / Control. Pearson correlation and simple linear model (y = a + bx) were used for determining the correlations between the relative changes in T_s, M_s, AGB and SOC and the relative changes in Re and Q_{10}.

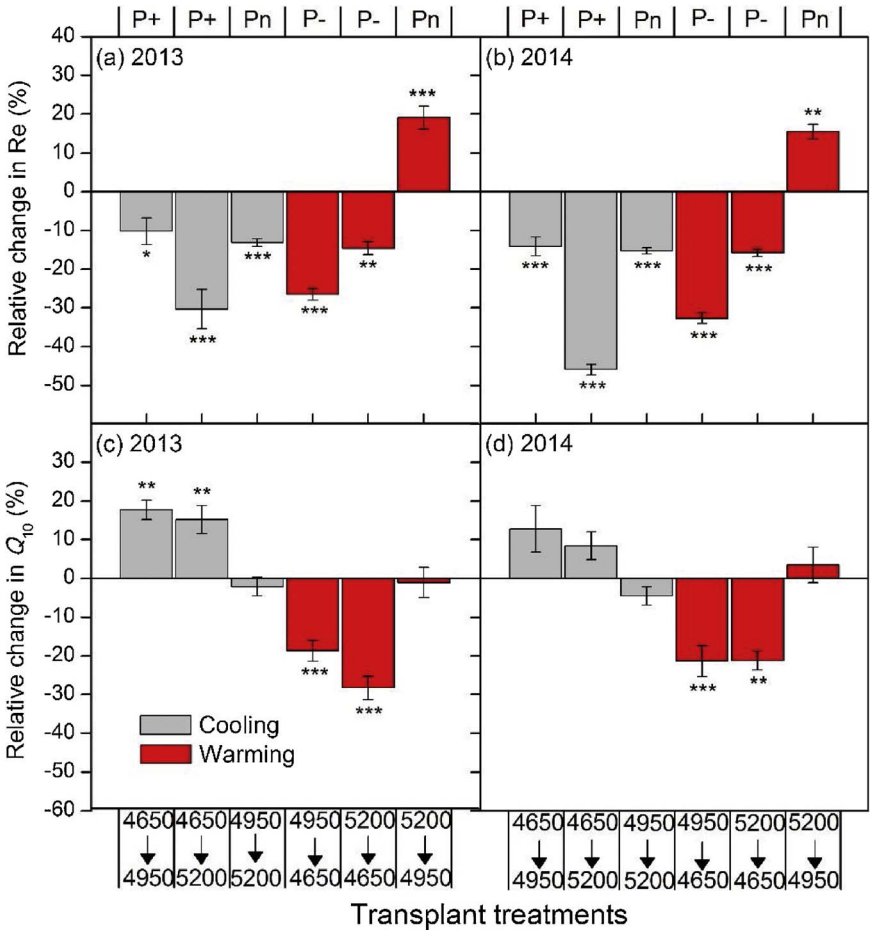

Fig. 5. The relative changes (%) in seasonal mean Re andQ_{10} between translocated sites and control sites (home-sites) along the altitudinal gradient. (a–b) The relative change in Re during 2013–2014; (c–d) the relative change in Q_{10} during 2013–2014. P +, precipitation increased; P–, precipitation decreased; Pn, precipitation unchanged. Mean ± SE is shown in error bars. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Table 2
Regression models ($Re = \alpha e^{bTs}$; $Re = \alpha M_s + b$) for relationships of seasonal ecosystem respiration (Re) to soil temperature (T_s) and soil moisture (M_s) at different treatments during 2013–2014. Parameters α and b are constant coefficients. R^2 and P are for the determination coefficient and statistical significance, respectively. NS, no significant difference; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Home site (m)	Destination site (m)	α	b	R^2	P
$Re = \alpha e^{bTs}$					
4650	4650	0.76	0.07	0.53	***
	4950	0.63	0.09	0.58	***
	5200	0.47	0.09	0.59	***
4950	4650	0.67	0.08	0.50	***
	4950	0.86	0.10	0.63	***
	5200	0.85	0.10	0.61	***
5200	4650	0.55	0.07	0.51	***
	4950	0.56	0.10	0.56	***
	5200	0.58	0.10	0.67	***
$Re = \alpha M_s + b$					
4650	4650	1.17	0.10	0.12	***
	4950	1.04	0.05	0.03	*
	5200	0.47	0.05	0.10	***
4950	4650	1.16	0.10	0.11	***
	4950	1.24	0.10	0.05	**
	5200	2.40	0.05	0.02	NS
5200	4650	0.81	0.07	0.11	***
	4950	1.24	0.05	0.03	*
	5200	1.38	0.04	0.03	*

All statistical analyses were performed using SPSS 19.0 (SPSS Inc., Chicago, Illinois, USA), and all significant differences were taken at $P < 0.05$.

3. Results

3.1. Microclimate conditions

Seasonal mean air temperature (GST) and soil temperature (T_s) significantly decreased with increasing altitudes, with a GST difference of approximately 2 °C between adjacent altitudes (Fig. 2 and Table 1). Growing season precipitation (GSP) and M_s were significant lower at 4650 m than at other two higher altitudes (Fig. 2 and Table 1).

3.2. Aboveground biomass and soil organic carbon

Aboveground biomass at the home sites was the highest at 4950 m (Table 1). Compared to the home sites, AGB generally decreased at the upward destination sites (Fig. 3a–b), and the experimental cooling had no significant effect on SOC (Fig. 3c–d). In the downward transplantation (warming), AGB and SOC decreased significantly at the drier destination sites (e.g., from 4950 m to 4650 m), but showed less changes at the wetter destination site (e.g., from 5200 m to 4950 m), as compared with the home sites (Fig. 3).

3.3. Ecosystem respiration

There were similar seasonal patterns of the Re across transplant treatments and observed years (Fig. 4a, c, e). In general, the upward transplantation (cooling) resulted in a decrease of the Re, as compared to the home sites (Figs. 4a–d and Figure 5a–b). The downward transplantation (warming) significantly decreased the Re at the drier destination sites (transplanted from 5200 m and 4950 m to 4650 m), but increased the Re at the wetter destination site (transplanted from 5200 m to 4950 m) (Figs. 4c–f and Figure 5a–b).

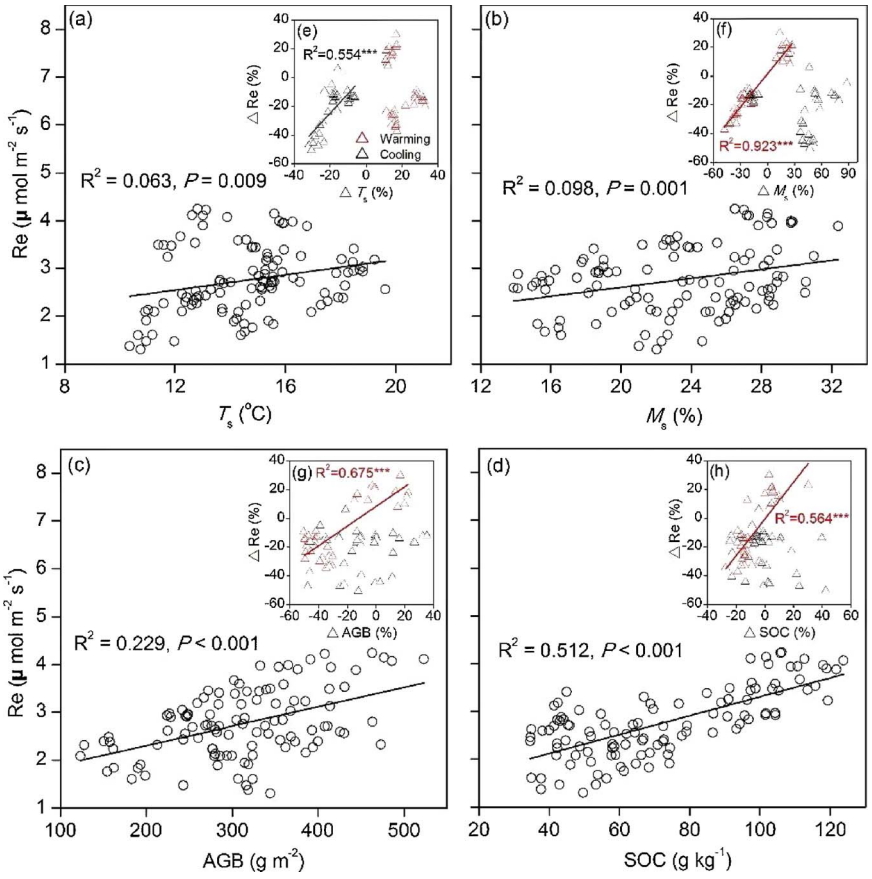

Fig. 6. Relationships of growing-season ecosystem respiration (Re) to (a) soil temperature (T_S), (b) soil moisture (M_S), (c) aboveground biomass (AGB), and (d) soil organic carbon (SOC). Insert: the relationships between transplant-induced changes in (e) Re and T_S, (f) Re and M_S, (g) Re and AGB, and (h) Re and SOC. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Over the growing season, the Re in general showed a significant exponential relationship with T_s, but a weak linear relationship with M_s (Table 2). In pooled data across home and destination sites, Re was positively correlated with T_s, M_s, AGB or SOC (Fig. 6a–d). For the warming treatment (downward transplantation), the relative change in the Re was positively correlated with the changes in M_s, AGB or SOC, but showed no significant correlation with the change of T_s (Fig. 6e–h). For the cooling treatment (upward transplantation), however, the relative change in the Re only showed a significant relationship with the change of T_s (Fig. 6e–h).

3.4. Temperature sensitivity of Re (Q_{10})

The downward transplantation (warming) generally decreased Q_{10} while the upward transplantation (cooling) increased Q_{10}, except for the translocations between 4950 and 5200 m (Fig. 5c–d). In pooled data across home and destination sites, Q_{10} declined with increasing T_s, but increased with increasing M_s, SOC or AGB (Fig. 7a–d). Compared to the home sites, the relative change in Q_{10} was negatively correlated with the change of T_s, but positively with the changes of M_s or SOC (Fig.7e–h).

4. Discussion

4.1. Effects of warming and cooling on ecosystem respiration

Experimental warming affects the Re possibly through influencing soil temperature, soil moisture, plant growth, and other processes involved in soil respiration (Li et al., 2013a; Lu et al., 2013; Wang et al., 2014). In alpine meadows, however, it has been reported that experimental warming may increase (Hu et al., 2016; Chen et al., 2017), decrease (Fu et al., 2013) or have no significant effect on the Re (Lin et al., 2011;Chen et al., 2016a). In this study, we found that the experimental warming increased the Re only when water availability also increased (Fig. 5a–b). Since AGB were positively correlated with the Re (Fig. 6c), the increased Re under the warming can be partly attributed to the increase of autotrophic respiration caused by the higher AGB after the transplantation. Moreover, the increased SOC by the experimental warming also possibly contributed to the increased Re (Fig. 6d).

On the other hand, the experimental cooling generally decreased the Re in this study (Figs. 4 and 5), being consistent with previous studies (Hart, 2006; Hu et al., 2016). The Re was highly correlated with T_s but not with M_s (Fig. 6a–b). This result suggests that temperature rather than precipitation might be the major factor for the decreased Re under the experimental cooling. In high-altitude ecosystems, low temperature often limits water or nitrogen availability (Luo et al., 2005; Reich et al., 2006), or reduces plant biomass (Li et al., 2013b; Wang et al., 2013). Both the effects can result in a decrease of the Re, as observed under the experimental cooling in this study. The experimental cooling can also decrease heterotrophic respiration, which will further reduce the Re (Link et al., 2003; Luan et al., 2014). No significant change in SOC in our study can be ascribed either to the undetected SOC change by the current method, and/or to the low microbial activity in the alpine meadow.

4.2. Effect of altered precipitation on ecosystem respiration

Changes in precipitation can directly influence plant and microbial respiration, especially in water-limited ecosystems (Wan et al., 2007; Liu et al., 2009). In this study, the experimental warming effects on the Re were highly dependent on the precipitation change (Fig. 5a–b). Our data suggest that the warming effects on the Re require sufficient water availability to supply both autotrophic and heterotrophic respiration. On the other hand, the decreased precipitation resulted in the decrease of Re, which is possibly due to the limitation of microbial activities

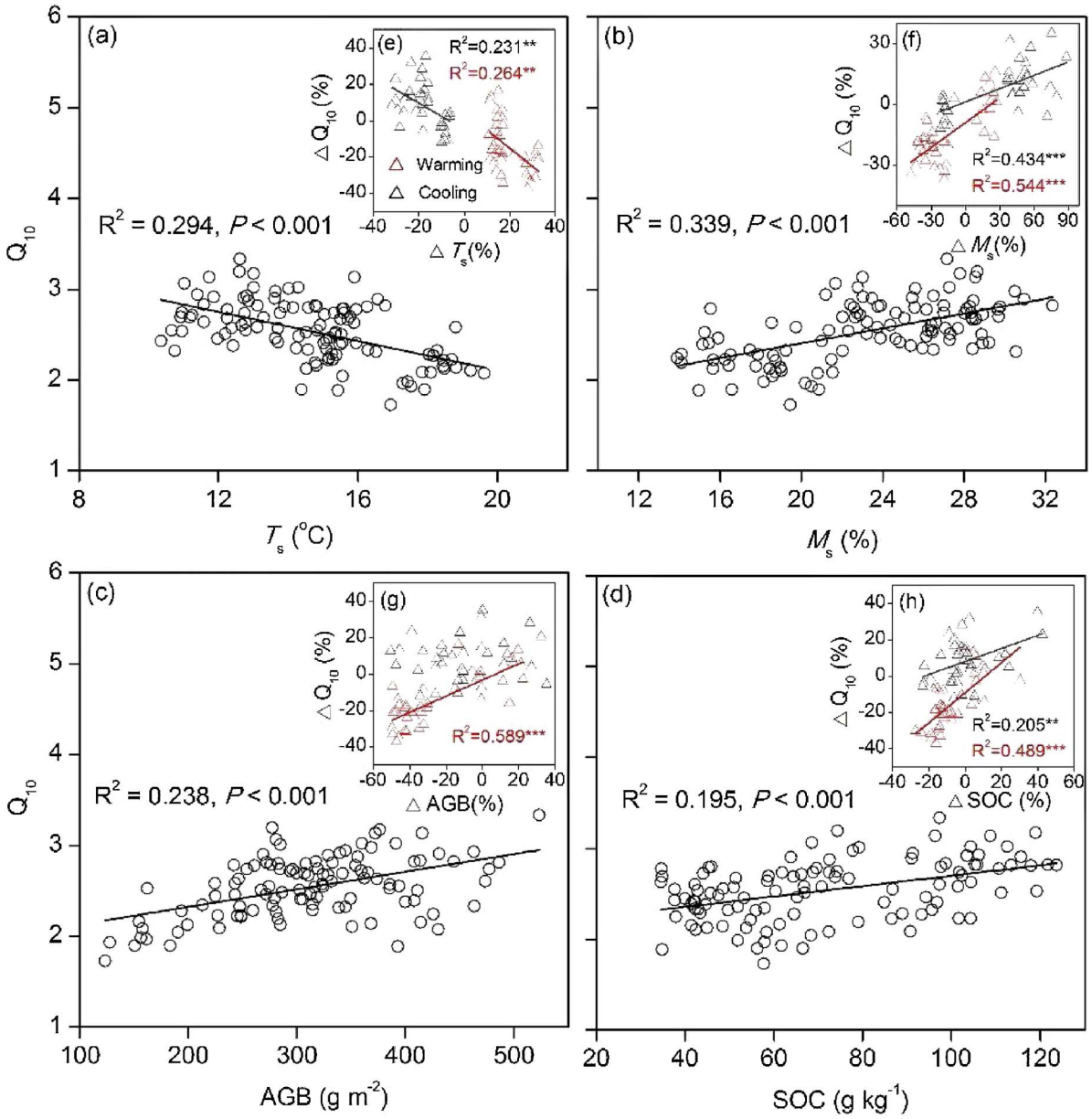

Fig. 7. Relationships of growing-season temperature sensitivity of ecosystem respiration (Q_{10}) to (a) soil temperature (T_S), (b) soil moisture (M_S), (c) above-ground biomass (AGB), and (d) soil organic carbon (SOC). Insert: the relationships between transplant-induced changes in (a) Q_{10} and T_S, (b) Q_{10} and M_S, (c) Q_{10} and AGB, and (d) Q_{10} and SOC. $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

caused by decreased soil moisture (Sardans et al., 2008; Liu et al., 2016), or because of the decreased autotrophic respiration under a lower soil water availability (Sardans et al., 2008; Wu et al., 2011).

The alpine ecosystems on the Tibetan Plateau usually suffer from water deficiency caused by high evapotranspiration, and climatic warming can further accelerate the water deficiency (Zhu et al., 2017). The decline of the Re under the combination of experimental warming and precipitation decreasing was probably due to the soil drying in this study, which is similar to a previous report from alpine ecosystems (Luo et al., 2008). Thus, the effects of precipitation change on the Re largely depend on temperature environments. When low temperature becomes a limiting factor, precipitation change would have little influence on plant growth and thus on the Re. Both this study and a previous study confirmed that increased precipitation has negative or no significant effects on plant biomass in temperature-limited ecosystem (Dormann and Woodin, 2002). Future studies may be needed to assess the critical point at which temperature and precipitation both limit the Re and how the threshold point varies with climate change.

4.3. Temperature sensitivity of ecosystem respiration

The Q_{10} values for the Re observed in our study are close to the range reported for other alpine ecosystems (Zheng et al., 2009; Lin et al., 2011). However, previous reports about warming effects on Q_{10} are controversial in alpine meadows, indicating positive (Hu et al., 2016) or negative (Lin et al., 2011; Fu et al., 2013) effects. Because water-limited ecosystems are sensitive to increased precipitation, Q_{10} may be mainly driven by warming-induced changes in soil moisture (Liu et al., 2016). In this study, Q_{10} decreased with the experimental warming and drying, but varied little when the downward transplantation resulted in no significant change in the precipitation and soil water, regardless of temperature changes (Fig. 5c–d). Our data further indicated that Q_{10} change was closely related to the change of M_s (Fig. 7b), suggesting that the decrease of Q_{10} under the experimental warming could result partly from the decrease of soil moisture. It is reported that warming-induced lower moisture may reduce Q_{10} through inhibiting the activity of the rhizosphere and soil microorganisms

(Wagle and Kakani, 2014). Also, the reduction of Q_{10} with the experimental warming could be attributed to the physiological acclimation in plant respiration and/or microbial activity, as reported in some studies (Luo et al., 2001; Atkin and Tjoelker, 2003). Under the increased temperature, microbes tend to consume labile substrate as an energy source, which requires less energy and results in lower Q_{10} (Lefèvre et al., 2014). We observed that Q_{10} was well correlated with SOC content (Fig 7d), suggesting that the increase in SOC decomposition might be a reason for reduction in Q_{10} in alpine meadows.

Cooling can increase (Li et al., 2017) or decrease (Hu et al., 2016) Q_{10} of the Re in alpine grasslands. We observed that Q_{10} of the Re increased significantly at upward destination sites in a cooler and wetter environment (Fig. 5c–d). Higher temperature sensitivity of respiration at low temperatures has been observed before, which is probably due to a change in microbial community composition in order to maintain high decomposition rates at low temperatures (Monson et al., 2006; Song et al., 2015). In addition, under the decreased temperature, microbes tend to consume more recalcitrant substrate, which requires greater activation energy and results in higher Q_{10} (Craine et al., 2010). Other biotic and abiotic factors, including responses of litter decomposition, microbial community, different soil carbon cools and belowground biomass to altered temperature and precipitation might also be involved in the changes of Re and Q_{10}, which deserves further studies.

5. Conclusions

We demonstrated that reciprocal transplant experiment is an effective approach to examine combined effects of temperature and precipitation on ecosystem respiration. Our observation indicated that cooling and warming effects on ecosystem respiration differ depending on precipitation change. Warming is likely to increase ecosystem respiration through increasing aboveground biomass if water availability is improved. The experimental cooling, however, tends to reduce ecosystem respiration through reducing soil respiration by low soil temperature. Such the interactive effects of warming and precipitation change on the ecosystem respiration must be taken into account in predicting carbon cycle in alpine meadow or other similar ecosystems.

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